Comparative study of biological and artificial neural networks

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ABSTRACT

In this research project, the features of biological and artificial neural networks were studied by reviewing the existing works of authorities in print and electronics on biological and artificial neural networks. The features were then assessed and evaluated and comparative analysis of the two networks was carried out. The metrics such as structures, layers, size and functional capabilities of neurons, learning capabilities, style of computation, processing elements, processing speed, connections, strength, information storage, information transmission, communication media selection, signal transduction and fault tolerance were used as basis for comparison. A major finding in the research showed that artificial neural networks served as the platform for neuro-computing technology and as such a major driver of the development of neuron-like computing system. It was also discovered that Information processing of the future computer systems will greatly be influenced by the adoption of artificial neural network model.

Keywords: Biological, Artificial, Network, Nuerons, Architecture, Metrics, Comparison

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INTRODUCTION

1.1 Background of the Study
The marriage of computing and communication technologies has given birth to Information Technology (IT) which is now the fastest growing industry in the world today. There are two major schools of thought in the Information Technology (IT) industry and these are:

a.   the school of thought that attempts to study Information Technology (IT) and use the knowledge acquired to build Information Technology (IT) based systems to enhance the performance of human experts in their problem domains and

b.   the school of thought that takes a study of the structure and function of the human body and attempts to use the knowledge acquired to build human-like intelligent computing system.

The research presents a platform on which the second school of thought operates. The major tools used for the building of the platform are Neural Networks (IEE Transactions 2000b, Neural Computing 2002, Statsoft Inc. 2002, Zapron Systems Inc. 2001) and Fuzzy Logic [4]. The human system and computing system have as their nerve centre the brain and computer (Central Processing Unit (CPU)) respectively. The computer is capable of executing efficiently arithmetic and logic operations while the brain is efficient in executing operations that involve pattern recognition and matching [10]. The brain recognizes and acts on constantly changing patterns of input stimuli.

In the past years, the computing industry has attempted to make a computer that treats information as patterns in the same way that the brain does. The trends of the developments in the computing industry over the years are as follows:

1950 - 1970: The emphasis was on the science of computing and the major development was the processing of numeric data.

1971 - 1980: The emphasis was on the engineering of computing and the major breakthrough was the processing of text data. Computers were being used for word processing, type setting and desk top publishing.

1981 - 1990: The emphasis was on the re-engineering of computing and the major development was the processing of image and graphic data. During this period, computers were being used to draw multidimensional graphs, scan, store, verify and validate images, signatures and classified documents.

1991 to date: The emphasis has been on the technology of computing and the major development has been audio and video processing. During this period, a class of computing system described as multimedia system emerged and the development brought about the situation whereby the dividing line between a digital computer and an analog computer no longer exist.

The important development in the computing industry between 1950 and 1990 has John Von Neumann architecture as their platform. The major characteristics of the architecture are as follows:

a. Computing system that operates on discrete signals.

b. Memory system that records discrete signals to be processed, a sequence of specific instructions that serially processes the signals and produces the output reports.

c. Computing system that operates by a continuous cycle of fetching an instruction from the memory, executing the instruction and storing the result of the instruction in the memory.

d. Computing system which emphasizes the efficient and primitive performance of the computer rather than the efficient and intelligent performance of the brain of the human being which uses it. Computing systems were used to automate the operations of human experts, as such, it was considered as an alternative rather than a partner to human experts [1].

Furthermore, recent development is aimed at building computing system that will operate intelligently like the human brain. The computing system of today emphasizes the efficient and intelligent performance of the computer users. It, therefore, facilitates the interactive processing of information in a manner that is intelligent, menu and dialogue driven [1, 4].

This has consequently brought about a challenge on the study of neural networks. A neural inspired by the structure and function of biological neural system. A neural network that attempts to mimic the functions of the biological central nervous system and some of the sensory organs attached to it.

MATERIALS AND METHODS

1.2 Methodology

The existing works of authorities in prints and electronics on biological and artificial neural networks were reviewed. The review work involves a study of the structure and function of both neural networks.

The features of both biological and artificial neural networks were assessed, evaluated and compared with a view to drawing the matrix of equivalence of the features. Neural Networks metrics such as structures, layers, size of neurons, functional capabilities of neurons, their learning capabilities, style of computation, processing elements, processing speed, connections, strength, information storage, information transmission communication media selection, signal transduction and fault tolerance were used as basis for comparison. The principles and practice of neuro-computing was studied with a view to showing the applications of neural networks in the development of human-like intelligent computer software system

1.3 Objective of the research

The primary objective of this study is to establish the potential features of biological neural network that can be adapted for the development of human-like intelligent computer system

2. General Overview

Research in the field of neural networks has been attracting increasing attention in recent years. Since 1943, when Warren McCulloch and Walter Pitts presented the first model of artificial neurons, new and more sophisticated proposals have been made from decade to decade[11, 13,14]. Mathematical analysis has solved some of the mysteries posed by the new models but has left many questions opened for future investigations [3] [6]. Needless to say, the study of neurons, their interconnections and their role as the brain's elementary building blocks is one of the most dynamic and important research fields in modern biology.

2.1 Models of Computation
Artificial neural networks can be considered as just another approach to the problem of computation. The first formal definitions of computability were proposed in the 1930s and '40s and at least five different alternatives were studied at the time. The computer era was started, not with one single approach, but with a contest of alternative computing models. It is we all know that the von Neumann computer emerged as the undisputed winner in this confrontation, but its triumph did not lead to the dismissal of the other computing models.
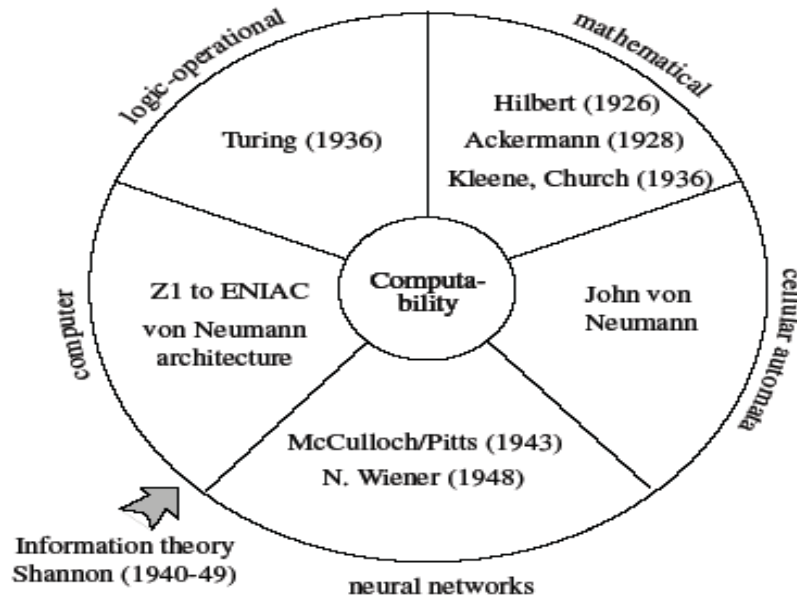

Fig. 1The biological model (neural networks)

The explanation of important aspects of the physiology of neurons set the stage for the formulation of artificial neural network models which do not operate sequentially, as Turing machines do. Neural networks have a hierarchical multi-layered structure which sets them apart from cellular automata, so that information is transmitted not only to the immediate neighbors but also to more distant units. In artificial neural networks one can connect each unit to any other. In contrast to conventional computers, no program is handed over to the hardware – such a program has to be created, that is, the free parameters of the network have to be found adaptively.

Although neural networks and cellular automata are potentially more efficient than conventional computers in certain application areas, at the time of their conception they were not yet ready to take center stage. The necessary theory for harnessing the dynamics of complex parallel systems is still being developed right before our eyes. In the meantime, conventional computer technology has made great strides.

Artificial neural networks have, as initial motivation, the structure of biological systems, and constitute an alternative computability paradigm. For that reason it is necessary to review some aspects of the way in which biological systems perform information processing. The fascination which still pervades this research field has much to do with the points of contact with the surprisingly elegant methods used by neurons in order to process information at the cellular level. Several million years of evolution have led to very sophisticated solutions to the problem of dealing with an uncertain environment. In this study, some elements of these strategies were discussed in order to determine what features to adopt in the abstract models of neural networks.

2.2 Biological Neural Networks
Nervous system
The nervous system as a network of cells specialized for the reception [7], integration and transmission of information. It comprises the brain and spinal cord (the central nervous system; CNS) and sensory and motor nerve fibres that enter and leave the Central Nervous System (CNS) or are wholly outside the CNS (the peripheral nervous system; PNS). The fundamental unit of the nervous system is the neuron.

There are about 1011 neuron in the body. Their cell bodies tend to aggregate into compact groups (nuclei, ganglia) or into sheets (laminae) that lie within the grey matter of the central nervous system (CNS) or are located in specialized ganglia in the peripheral nervous system (PNS). Groups of nerve fibres running in a common direction

usually form a compact bundle (nerve, tract, peduncle, brachium, and pathway). Many of these nerve fibres are surrounded by sheaths of lipid material called myelin which gives rise to the characteristic appearance of the white matter. In addition to neurons there are glial cells which play a supporting role. There are about 10 times more glial cells than neurons and they occupy approximately half the volume of the brain.

Summarily neurons are specialized;
a.   to receive information from the internal and external environment;
b.   to transmit signals to other neurons and to effector organ;
c.   to process information (integration) and
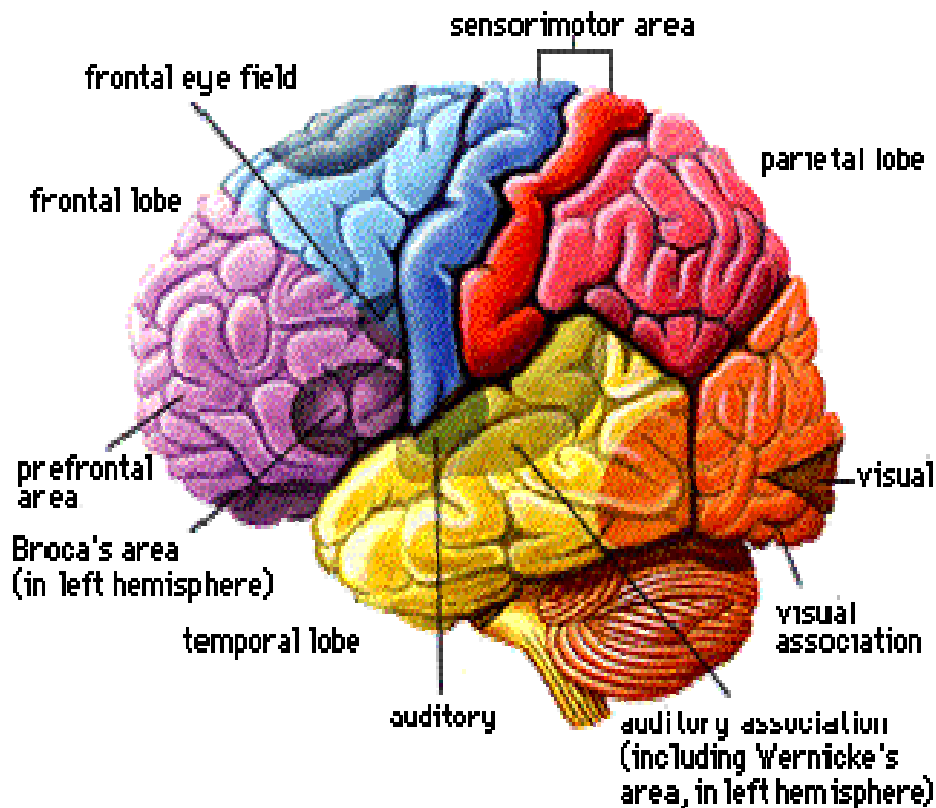d.   to determine or modify the differentiation of sensory receptor cells and effector cells.
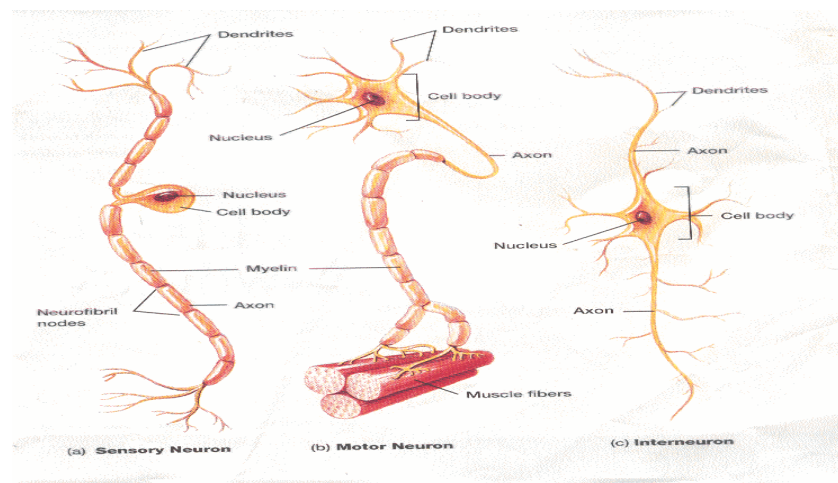

Fig. 2 Typical Human Brain

Fig. 3 The Typical Types of Neurons

3 Motivation for Artificial Neural Networks
Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques. A trained neural network can be thought of as an "expert" in the category of information it has been given to analyze. This expert can then be used to provide projections given new situations of interest and answer "what if'' questions.

Other advantages of artificial neural networks include:
a.   Adaptive learning: An ability to learn how to do tasks based on the data given for training or initial experience.
b.   Self-Organization: An ANN can create its own organization or representation of the information it receives during learning time.
c.   Real Time Operation: ANN computations may be carried out in parallel, and special hardware devices are being designed and manufactured which take advantage of this capability.
d.   Fault Tolerance via Redundant Information Coding: Partial destruction of a network leads to the corresponding degradation of performance. However, some network capabilities may be retained even with major network damage.
4 Architecture of Neural networks
The architecture can be any of the following types:
a.   Feed-forward Networks
b.   Feedback Networks
c.   Multilayer perceptron

4.1 FEEDFORWARD NETWORK
Feed-forward Networks allow signals to travel one way only; from input to output. There is no feedback (loops) that is the output of any layer does not affect that same layer. Feed-forward Networks tend to be straight forward networks that associate inputs with outputs. They are extensively used in pattern recognition. This type of organization is also referred to as bottom-up or top-down. A typical feed forward neural network is presented in Fig. 4
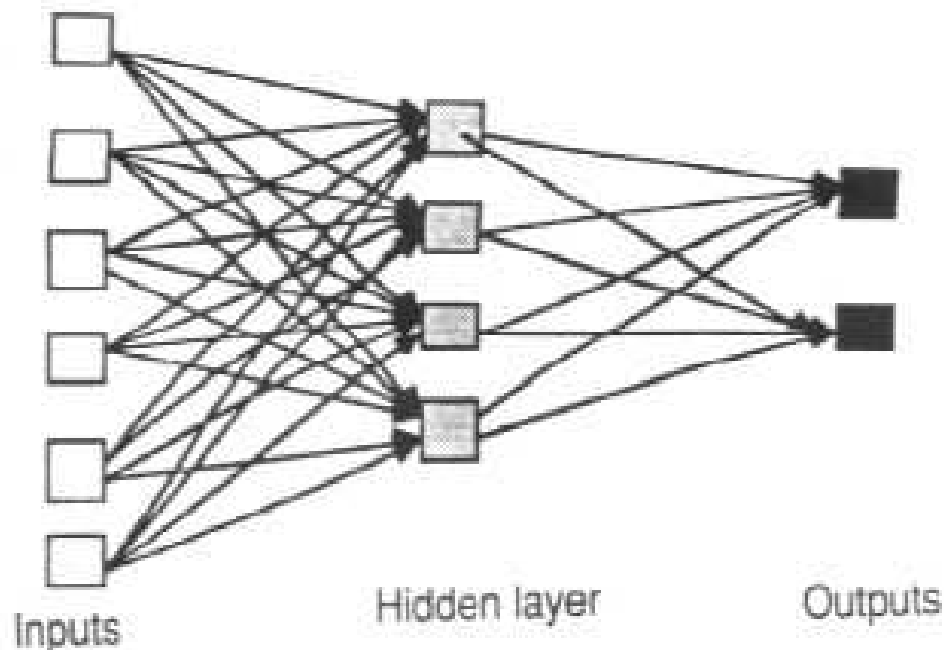■   .

Fig. 4 Feed forward Architecture

4.2 Feed Back Networks
Feedback networks can have signals traveling in both directions by introducing loops in the network. Feedback networks are very powerful and can get extremely complicated. Feedback networks are dynamic; their 'state' changing continuously until they reach equilibrium point. They remain at the equilibrium point until the input changes and a new equilibrium needs to be found. Feedback architectures are also referred to as interactive or recurrent, although the latter term is often used to denote feedback connections in single-layer organizations
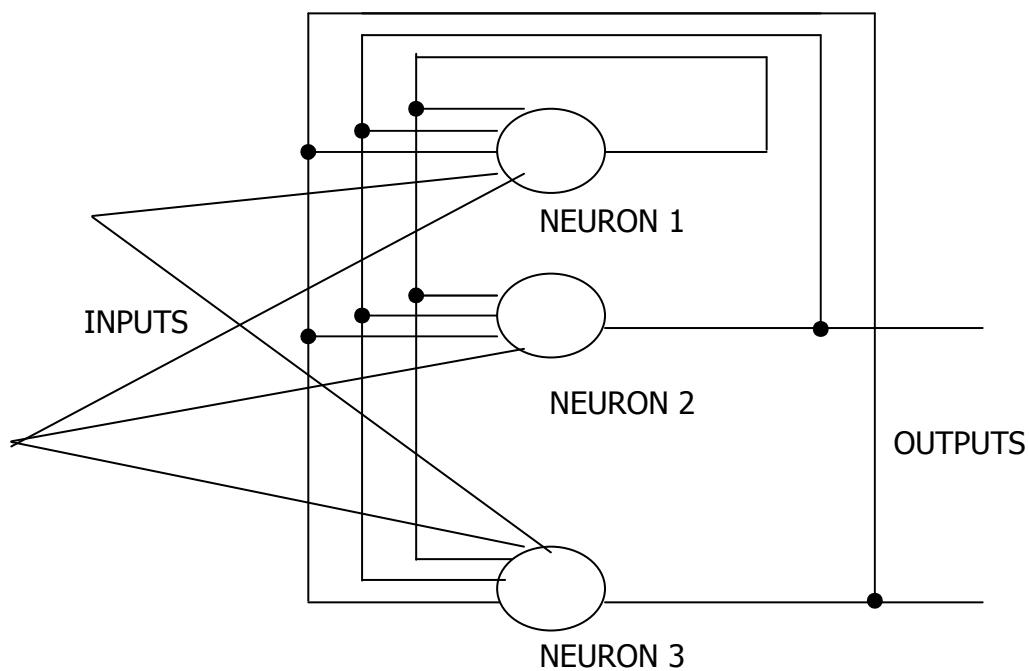
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Fig. 5 Feedback Architecture

Input Signal   Output Signal

Input Layer   Hidden layer   Hidden layer   Output Layer
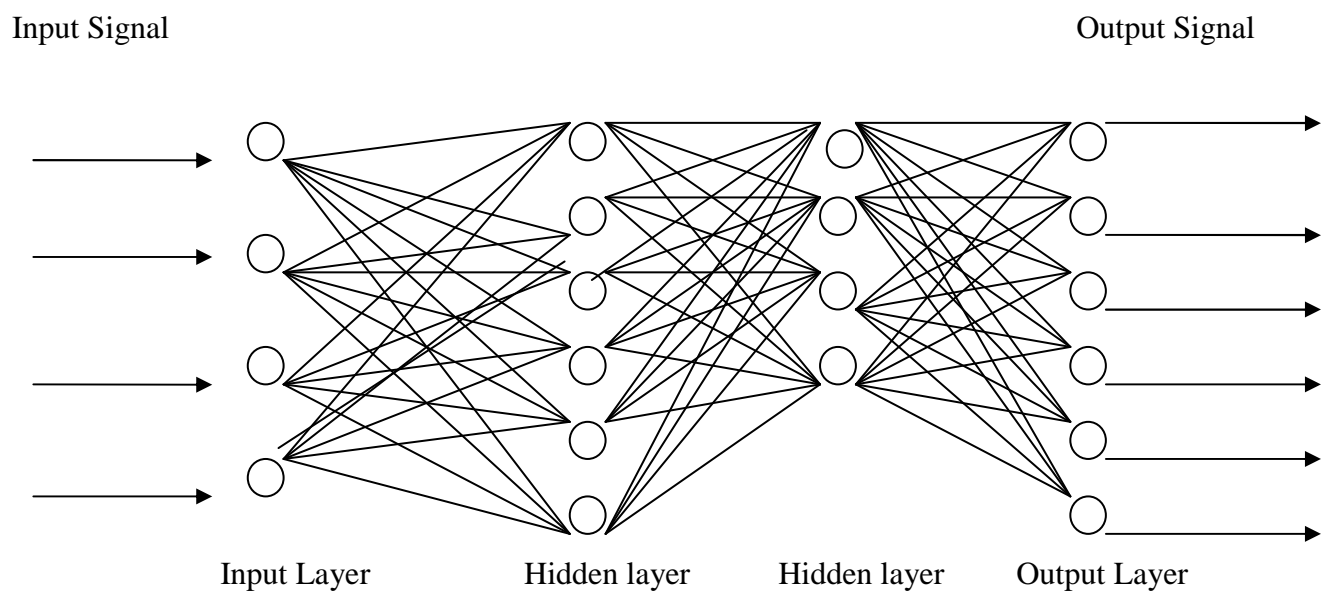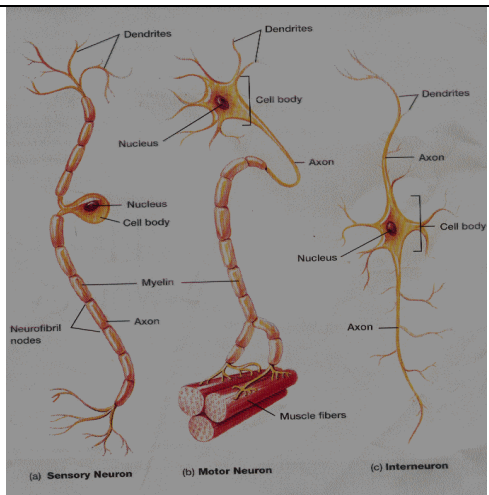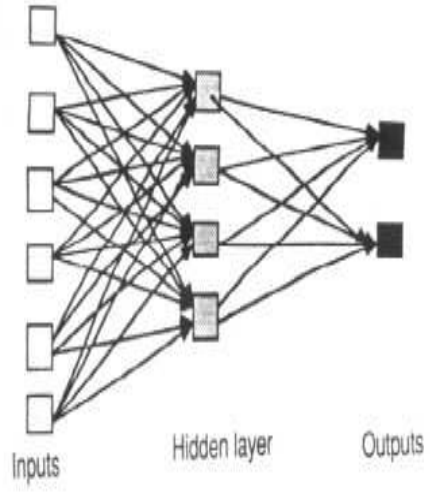
Fig 6 Multilayer Perceptron Architecture

4.3 Multilayer Perceptron
According to [8], the multilayer perceptron is the most popular network architecture in use today; the architecture has been discussed extensively in [5]. This is the type of network in which the units perform a biased weighted sum of their inputs and pass the activation level through a transfer function to produce their output, and the units are arranged in a layered feed-forward topology. The network thus has a simple interpretation as a form of input-output model, with the weights and thresholds (biases) the free parameters of the model. Such networks can model

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functions of almost arbitrary complexity, with the number of layers, and the number of units in each layer, determining the function complexity. Important issues in Multilayer Perceptron (MLP) design include specification of the number of hidden layers and the number of units in these layers [15]; [9].

5 Comparative Analysis

Structure	
BIOLOGICAL NN	ARTIFICIAL NN
  Biological Neural Networks have the following parts. ■ - Soma present ■ - Dendrites present ■ - Synapse present ■ - Axon present ■ Neurons have three main parts: a central cell body, called the soma, and two different types of branched, treelike structures that extend from the soma, called dendrites and axons. ■ - Information from other neurons, in the form of electrical impulses, enters the dendrites at connection points called synapses. The information flows from the dendrites to the soma where it is processed. The output signal, a train of impulses, is then sent down the axon to the synapse of other neurons.	 Artificial Neural Networks also have the following components that are equivalent to Biological Neural Networks. ■ - Node present ■ - Input present ■ - Weight present ■ - Output present ■ The main body of an artificial neuron is called a node or unit. They are physically connected to one another by wires that mimic the connections between biological neurons. ■ - The arrangement and connections of the neurons made up the network and have three layers. The first layer is called the input layer and is the only layer exposed to external signals. The input layer transmits signals to the neurons in the next layer, which is called a hidden layer. The hidden layer extracts relevant features or patterns from the received signals. Those features or patterns that are considered important are then directed to the output layer, which is the final layer of the network.
Layers	
■ Biological neural networks are constructed in a three dimensional way from microscopic components. These neurons seem capable of nearly unrestricted interconnections	■ In the Artificial neural networks , this is not true. These are the simple clustering of the primitive artificial neurons. This clustering occurs by creating layers, which are then connected to one another. The layers connection may also vary. Basically, all artificial neural networks have a similar structure of topology.
Size	

■ 10^{11} neurons	■ $10^2 - 10^4$ neurons

Functions

■ - Dendrites provide input signals to the cells. ■ - A synapse is able to increase or decrease the strength of the connection. This is where information is stored. ■ - The axon sends output signal to another cell. The axon terminals merge with the dendrites of the other cells. ■ - The brain is made up of a great number of components (about 1011), each of which is connected to many other components (about 104), each of which performs some relatively simple computation, whose nature is unclear, in slow fashion connections.	■ - The artificial neuron receives inputs analogous to the electrochemical impulses the dendrites of biological neurons receive from another neuron. ■ - The artificial signals can be changed by weights in a manner similar to the physical changes that occur in the synapses. ■ - The output of the artificial neuron corresponds to signals sent out from biological neuron over its axon. ■ - In connectionism, neurons are connected randomly or uniformly, and all neurons perform the same computation. Each connection has associated with it a numerical weight. Each neuron's output is a single numerical activity which is computed as a monotonic function of the sum of the products of the activity of the input neurons with their corresponding connection weights.

Learning

■ They are able to tolerate ambiguity, to learn on the basis of very impoverished and disorganized data [for example, to learn a grammar from random samples of poorly structured, unsystematic, natural language]. ■ - They learn from past experience to improve their own performance levels. ■ - Learning in biological systems involves adjustments to the synaptic connections that exist between the neurones.	■ - More precisely formatted and structured data and rules are required. ■ - They also learn from past experience to improve their own performance levels. ■ - This is true of Artificial Neural Networks as well.

Style of   computation

■ Biological neural networks communicate through pulses, the timing of the pulses to transmit information and perform computation. (Parallel and distributed).	■ Artificial neural networks are based on computational model involving the propagation of continuous variable from one processing unit to the next. (Serial and centralized).

Processing   elements

■ Processing abilities follow highly parallel processes operating on representations that are distributed over many neurons. ■ - Network of neurons in the brain form a massively parallel processing system. ■ - 10^{14} Synapses	■ Processing abilities captured highly parallel computation based on distributed representations. ■ - The model emulates a biological neural network. ■ - 10^8 Transistors

Processing speed

■ Slow – neurons need several milliseconds to react to stimulus. ■ - The elementary 'cycle time' of neurons [that	■ - Fast – this can achieve switching times of a few nanoseconds. ■ - Silicon gate times are on the order of one

is, their time constant] is of the order of one millisecond. (100 Hz).	nanosecond, that is, a million times faster. (109 Hz).
Fault tolerance	
■ Its performance tends to degrade gracefully under partial damage. This means that partial recovery from damage is possible if health units take over the functions previously carried out by the damaged areas.	■ It has the potential to be fault tolerant, or capable of robust performance, in the sense that its performance degrades gradually under adverse operating conditions.
Connection	
■ Much higher number of connections between neurons. ■ - Neural tissue involves random connectivity with no master blueprint.	■ - Less edges but often fully connected topology. ■ - Connectivity is precisely specified.
Strength	
■ Other factors like neuro- transmitter influencing synapse strength.	■ Synapse strength determined by weight only.
Information storage	
■ It is stored at the synapses.	■ It is stored at the weights matrix.
Information transmission	
Neurons transmit information using electrical signals	Also transmit information using electrical signals
Communication media selection	
Communications media in neural tissue involve stochastic.	They are deterministic and formally structured.
Signal Transduction	
■ Pulse coded signal transduction [frequency modulation]. ■ - Time delayed transduction. ■ - Neural tissue is asynchronous, and there is no master clock. .	■ Numerical activation value [amplitude modulation]. ■ - Temporal factors of signal transduction neglected. ■ - Time is an analog [continuous] variable.

RESULTS

6 Findings
The following are the similarities and differences of the networks

6.1 Similarities
a.   Biological neural networks process information in parallel; this is also true of artificial neural networks.

b.   Learning in biological neural networks is through past experiences which improve their performance level; this is also true of artificial neural networks.
c.   Learning in biological neural networks involves adjustment of the synaptic connections; learning in artificial neural networks is also by adjustment of weights. Weight in artificial neural networks is similar to synapse in biological neural networks.
d.   Information transmission in biological neural networks involves using electrical signals. In artificial neural networks, electrical signals are also used in information transmission.
e.   Information storage in biological neural networks is at the synapses, in artificial neural networks information is also stored in weights matrix.

6.2 Differences

a.   Information processing in biological neural networks is usually slow; this is because neurons need several milliseconds to react to a stimulus. In artificial neural networks information processing is very fast because electronic gates which they use to operate can achieve switching times of a few nanoseconds.
b.   Nevertheless the brain is capable of solving problems which no digital computer can yet efficiently deal with.
c.   Biological neural networks are constructed in a three dimensional way from microscopic components which are capable of nearly unrestricted interconnection. Artificial neural networks are the simple clustering of the primitive artificial neurons, this clustering occurs in layers which vary.
d.   Biological neural networks connect massive neurons of the order of 1011 neurons while artificial neural networks connect few neurons of the order of 102 to 104 neurons.
e.   There is much higher numbers of connections between biological neurons which involves random connectivity with no master blueprint. In artificial neural networks there is less edges and connectivity is precisely specified that there is a blueprint for their connection.
f.   Performance tends to degrade gracefully under partial damage in biological neural networks while artificial neural networks has the potential to be fault tolerant, that is capable of robust performance.

CONCLUSIONS

The following conclusions were drawn from the study:
 i.   Neural Networks attempt to bring computers a little closer to the brain's capabilities by imitating aspects of information in the brain in a highly simplified way. Although neural networks as they are implemented on computers were inspired by the function of biological neurons, many of the designs have become far removed from biological reality.
 ii.   The understanding of biological nervous systems inspired the concept of Artificial Neural Networks (ANN), a form of information processing. Just as a biological nervous system is a massive interconnection of nodes (called neurons) located within the brain, ANN consists of numerous interconnected processing elements that simultaneously work to solve specific problems. Usually created for specific applications, neural networks are ideal for data classification and pattern recognition problems. Mankind, having studied the brain for thousands of years, it was only natural that advances in electronics would entice man to try and understand and emulate its processes of problem solving, understanding, memorizing, and so on.
 iii.   Biological and artificial neural networks demonstrate the property of "graceful degradation", that is, destruction of individual neurons or of small groups of neurons reduces performance, but does not have the devastating effect that destroying the contents of a computer memory location would have.
 iv.   A very real difficulty of correlating artificial neural networks with biological neural networks lies in the way weights and synaptic strengths were modified. Weights are altered mathematically in a computer network, based on differences in values. Synaptic strengths on the other hand, are modified in response to synaptic activity. The back propagation model, in particular, is held to be biologically unrealistic so far as it would require a supervisor and a violation of the unidirectional flow of information seen in axons.
 v.   Simple feed-forward systems behave similar to biological neurons and focused on pattern recognition. Once the input layer values of the neurons are sets, the neuron determines the output, layer by layer. The dependence output values on input values requires adjusting every weight and threshold, which can be complex and time consuming. After training is complete, the network is able to supply reasonable outputs for any type of input, even if it does not match the training data. In that case, it attempts to determine the best output depending on its training method. Learning algorithms are available that take the inputs, adjust the weights and produce the required output.
 vi.   The key idea behind neural network is that they can take in a lot of data, process it in parallel, and provide accurate output, much as the human brain does. For example, when you see a goat, you know right away that it is a goat. You don't have to stop and count legs or look at the shape and colour. You process all of that data at the same time to know that you see a goat. That's what an artificial neural network does for a computer system.

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